Int J Life Cycle Assess (2008) 13:526–531
DOI 10.1007/s11367-008-0036-6

LETTER TO THE EDITOR

The need for a computational structure of LCC

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Received: 25 September 2008 / Accepted: 26 September 2008 / Published online: 16 October 2008

1 Problem overview

The opportunities for cost reduction often lie beyond the company gates, i.e., along the supply chain. The same happens with regard to the environmental burdens: Porter and van der Linde (1996) claimed that organizations should trace their own and other life cycle actors' emissions and disposal activities back into company activities to gain insight about beneficial product design, raw material, or process changes. Thereby, integrated supply chain management (SCM), life cycle costing (LCC), and analytical environmental management tools like life cycle assessment (LCA) are based on similar holistic approaches (Seuring 2004a). Their common objective is to allow, to a different extent, upstream and/or downstream processes to be included within the boundaries of the manufacturing system being analyzed. This combination of the involved supply chain actors' viewpoints is called a life cycle viewpoint. For the purposes of eco-efficient management of manufacturing systems, it is desirable to seek synergies among the aforementioned tools. From an environmental management accounting (EMA) perspective, such synergies are expected to focus on the identification and exploitation of both internal and external linkages along the industrial value chain. This is not warranted by the current practice of combining separate environmental and economic analysis, mainly based on LCA and LCC, respectively.

It emerges clearly that, within the taxonomy proposed by Rebitzer and Hunkeler (2003), the actor's perspective from which such issues arise is that of the producer. In this perspective, it is argued here that explicitly addressing a possible computational structure of LCC to be used consistently with LCA, or environmental LCC, would instead help one to overcome, at least theoretically, some methodological and implementation inconsistencies among LCC, LCA, and SCM. Such inconsistencies, as will be discussed here, are mainly related to aspects underlying the prevailing concept of environmental LCC, namely:

1. If understood only as a discounted cash flow analysis, LCC may prove to be inappropriate for taking into account commodities other than durable assets (which can well be analyzed by LCA and SCM, instead).
2. When it comes to assess costs, the insight into how the underlying information about material flows have been collected, organized, and computed may (surprisingly) prove to be poorer than in LCA and SCM, as far as complex enterprise information systems are taken to be *already* in place, providing cost assignment criteria that need not be further questioned. Yet, such an assumption is far from always being verified.
3. As a corollary, more emphasis is placed on pointing out what costs, even those which cannot be quantified easily, are to be included in LCC rather than on investigating how they have been assigned to different products (and by-products). This leads to approaching environmental (let alone societal) LCC as an ever-increasing cost figure, which might not be appealing for businesses.[1]
4. In contrast to the need of reducing cut-offs in LCA (e.g., using hybrid methods), LCC may reveal that it is

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[1] Provided that business is interested in product profitability, it hardly seems possible that there are cost elements whose existence needs to be reminded to management accountants to avoid that they be missed.

neither possible nor useful to gain insight into the cost structure of all the supply chain actors. Despite this, the most remarkable effort to provide an analytical account of LCC has been achieved so far in the field of hybrid LCC.

Whether any of the above points occur or not—e.g., some non-durable good is analyzed without any possibility to further investigate suppliers' cost structure and, being that a small enterprise is involved, there is not any advanced cost accounting system to rely upon—environmental LCC is nonetheless expected to shed some light on both costs and the manufacturing system.

As a premise, attention is to be paid to the meaning of LCC, not only as a discounted, cash flow-based, asset management tool (Woodward 1997). Considering LCC as a cost accounting tool instead, it will be claimed that environmentally extended input–output analysis (IOA) can provide analytical support in its formulation, similarly to LCA and SCM. The analytical features such a structure should have in order to adequately serve the cost accounting purpose of one or more of the involved actors will not be illustrated in detail here, since they have been outlined elsewhere (Settanni et al. 2008).

2 Issues related to the computational aspects of LCC

The concept of LCC within EMA has been widely defined in the literature. It can be viewed as either a way of incorporating costs into LCA (Norris 2001; Shapiro 2001; White et al. 1996) or as a way of deriving the full environmental cost of products with the aid of LCA (Epstein 2008; Schaltegger and Burritt 2000; Epstein and Roy 1997). Aside from any reference to LCA, LCC in this sense is the projected financial consequences of environmentally relevant decisions throughout the product life cycle (Epstein and Wisner 2002; Bennett and James 1998; Kreuze and Newell 1994). The aim of this section is not to provide a definition of LCC to be used in EMA. Rather, it will highlight those features of current approaches to this topic that call for the outline of a formal computational structure of LCC, which has until now received little attention. These are: the use of either costing method or cash flow analysis, the accounting for material flows, and the orientation towards the supply chain (SC).

2.1 Costing methods versus cash flow analysis

The approach that prevailed so far is the combination of separate, yet consistent, LCC and LCA. They are seen as complementary tools, and their parallel implementation then excludes any formal integration of the former into the latter (Udo de Haes et al. 2004), though the production alternatives are ranked accordingly in a number of ways (Kicherer et al. 2007; Reich 2005; Huppes and Ishikawa 2005).

Within management accounting, LCC is a tool which aims to lower those costs that are likely to be incurred by any actor during the economic product life (Artto 1994; Shield and Young 1991). This depends on the choice among the alternatives involving product architecture (Fixson 2004; Asiedu and Gu 1998). This well-established concept of LCC as a discounted cash flow analysis has been borrowed by LCA practitioners, but actually deviates from some basic features of the LCA model (Huppes et al. 2004). Thus, invoking LCC as the economic counterpart of LCA seldom entails practical insights into how costs, especially the environmental ones, are assigned to processes and products. The meaningful information about relevant cost categories are, indeed, expected to be gathered relying on the involved actors' information systems (Hunkeler et al. 2008—see especially pp. 28, 42, and 46).

This assumption may pose serious difficulties where the availability of advanced information systems like activity based costing (ABC) cannot be taken for granted, as is the case for Italy (Bhimani et al. 2007). Besides this, the main consequence of this assumption is that the underlying cost-tracing mechanism is often neither questioned nor performed explicitly within the analysis. According to the prevailing literature on environmental LCC, this might not appear to be the main concern, even if the producer's or SC perspective is adopted. Rough cost estimations have indeed been justified as due to the comparative nature of LCC (Rebitzer et al. 2003). Yet the question goes beyond the difficulties that may arise in gathering data which is necessary to perform an environmental LCC even within a specific firm or SC, and appears to be more related to the idea of a "generally applicable" standard LCC that does not necessary require company-specific cost figures in order to be implemented. After Hunkeler et al. (2008), LCC does not indeed replace traditional detailed cost or management accounting practices, but instead relies on it. Consequently, the identification and management of cost drivers, which lead to company-specific cost figures, is not in the focus of environmental LCC *per se*, being rather a matter of ABC, for instance.

By contrast (and unlike site-independent LCA), knowing exactly the role the cost accounting mechanism plays in the appropriate management of specific costs in a life cycle perspective is of vital concern for the manufacturing firm. On the one hand, this has been highlighted for both conventional LCC (see Hansen and Mowen (2003, chap. 13) and Fabrycky and Blanchard (1991, chap. 7)) and LCA-based LCC (Hansen and Mowen 2003, chap. 19). This issue could be of less importance, however, only if

LCC is just used, coupled with environmental indicators, to assess durable asset investments from the purchaser perspective on the basis of the associate cash outflows—this seems to be the far more widespread use of these tools.

If the perspective is one of the manufacturing firm, instead, LCC as an economic planning tool must be designed to aid management towards taking informed actions. Then its computational structure is to highlight LCC's unexploited potential as both a hindsight and foresight costing method that can address the entire cost structure of the company as well as any other cost object (Emblemsvåg 2003). Cash flow analysis should enter the LCC model only if an investment is being assessed and clear assumptions about the funding structure have been made. Otherwise, the use of discounted cash flow analysis instead of costing methods, on the one hand, would not be appropriate to keep track of resource consumption (Emblemsvåg 2001). On the other hand, cash flow analysis only allows the parallel implementation of LCA and LCC so far as investment decisions for durable assets are at stake and, thus, it narrows the scope of LCC *a priori*—yet, examples of combined LCA and LCC applied to commodities other than durable assets exist, like the one provided by Notarnicola et al. (2004). Besides the investment hypothesis, the choice of a discount rate would be arbitrary. For example, if cost discounting aims at reflecting the uncertainty associated with the occurrence of costs and environmental impacts over a significant period of time, then uncertainty should be properly taken into account, instead, by characterizing the model parameters with the associated probability distributions (Bras and Emblemsvåg 1995) and formulating scenario analysis (Hellweg et al. 2003).

2.2 Accounting for material flows

As to manufacturing firms, costs and environmental burdens are influenced to a great extent by the management of material flows, despite the fact that cost-cutting activities usually concentrate on personnel costs (BMU and UBA 2003). From an accounting perspective, EMA recognizes it to be crucial to integrate physical and monetary issues in the extent the former can have significant repercussions on the latter (Burritt et al. 2003). The computational structure of LCC should then assure that the black box view of the firm is resolved. To do so, the material flows underlying a system throughout its life cycle, as well as other operating parameters of the relevant manufacturing processes, are recognized as the appropriate cost drivers not only to assign the environmental costs to products (Senthil et al. 2003) but also to perform better management accounting (Jasch 2003).

Hunkeler et al. (2008, p. 38) correctly remark that elements which are relevant for the environmental assessment may be irrelevant for the economic assessment and vice versa; nevertheless, they can be included without violating the required condition that the system boundaries are to be the same. Provided that the life cycle inventory provides a good basis for deriving the costs associated with material and energy flows directly (Rebitzer 2002) and that LCA and LCC may be different in scope, the inventory has to be set up according to specific criteria that also suit the need of cost accounting.[2]

It is here argued that input–output analysis (IOA) can be applied to costing methods like LCC. It formalizes the structure of the underlying relationships among the reciprocally linked production units within the manufacturing system considered.

More importantly, environmental extensions of IOA have been widely discussed in literature that provide a well-grounded and transparent analytical criteria to deal with the material-flow-based assignment of end-of-pipe treatment/abatement costs to processes and then to products.

The analytical ground of IOA has been developed in the field of macroeconomics. Due to its properties, however, it has been shared to a different extent by those life-cycle-oriented methods, namely LCA (Heijungs and Suh 2002), SCM (Albino et al. 2002), and hybrid LCC (Nakamura and Kondo 2006). Nevertheless, IOA can also be effectively applied to solve several problems of cost accounting (Ijiri 1968), though the principles of macroeconomic IOA have to be adapted to meet the purposes of cost accounting and production planning (Gambling and Nour 1970).

To adopt a computational structure which is based on IOA is to model the structural elements of manufacturing processes, thus obtaining a basis for integrating production planning and costing methods that focus on business processes (Boons 1998).

This accounting scheme is especially useful in situations where a manufacturing system is made up of interacting processes and many or most of such processes require each other's outputs as inputs. The choice of the unit production processes which are linked by supplier/customer relationships reflects the sequence of operations to be performed and determines the system boundaries. The level of process detail depends upon the scope of the analysis. The net production of such a system can be described by using simultaneous equations that can be rendered in compact

[2] This would include: planning for different kinds of product models with constrained plant capacities; making a distinction among fixed cost drivers and cost drivers that vary according to the activity level of processes; allowing the calculation of the cost of producing waste and by-products, not only the cost of disposing it; taking beginning and final inventory of intermediate and final commodities, but also of raw materials into account.

matrix notation, consistently with that used in LCA (Heijungs and Suh 2002).

The model is built bottom upwards from the basic operations it purports to illustrate (Gambling 1968). Using matrices, it records flows among well-specified units—whether they are organizations or processes within the same organization. These physical relationships, including the environmental aspects, are then turned into financial transactions by means of matrix operations (Lin and Polenske 1998). Using one computational procedure, LCC based on IOA allows one to assess the system's activity levels, the expected resource requirement, the associated environmental burdens, and, consequently, the internal production costs, also along the supply chain. Once the inventory has been set up properly, the problem consists of calculating the expected number of process runs during the planning period so that the system's net production meets an exogenous production plan concerning a particular time period. They are based on basic linear algebra and are necessary to get a quantitative picture of the overall amount of resources—also pertaining to end-of-pipe processes—that will be required, produced, wasted, and recycled while meeting such production plans.

This foresight-oriented approach relies upon the anticipated performances of a manufacturing system and it has been defined as activity-level analysis (Heijungs 2001). It is consistent with other applications of IOA to cost planning at the enterprise level (Boons 1998; Livingstone 1969; Feltham 1968), and with standard costing as well.

2.3 Orientation towards the supply chain

The life cycle of a product is not an entity outside the control of the individual companies taking part in it (Seuring 2003). Integrated SCM, indeed, tends to integrate the product, relationship, and cost dimensions (Seuring 2002), while sharing the conceptual basis and the physical backbone of LCA (Seuring 2004b). Cost management techniques are required that allow transmitting the cost reduction pressure throughout the SC (Kajüter 2002), especially in the case of the greening of products (Seuring 2001). LCC seems consistent with such a perspective (James 2003; Rebitzer 2002). Modeling the reciprocal interdependences, in terms of linked material flows, among the echelons of an SC of production processes, should be secured by the computational structure of LCC. Starting from the focal company's boundaries, its scope should be gradually broadened, reflecting the actual relationships among SC partners. Issues that belong to interorganizational cost management can be addressed in this way. An example would be the reduction of the information asymmetry between the buyer and the supplier regarding the relationship between the specifications established by the former and the resulting costs to the latter (Cooper and Slagmulder 2004). This would also facilitate measuring the performances of a supply chain which has been extended to allow considerations for environmental concerns associated with waste and resource minimization (Beamon 1999). The concern of gathering cost information from different entities to implement LCC (Hunkeler et al. 2008; Schaltegger and Burritt 2000, p. 125) is thus constrained by actual SC relationships, and so is also the requirement of an alignment between LCA and LCC.

It may prove to be neither possible nor useful, indeed, to gain insight into the cost structure of other supply chain actors. Unless a joint effort to achieve cost savings beyond the influence of a single organization is feasible, it involves the management of drivers to control cost propagation through the supply chain. On the contrary, as the lesser flows in LCA are cut off, the analysis becomes more in-depth. Macroeconomic IOA merged with LCA has mainly served that aim (see, for example, Suh and Huppes 2005).

3 Final remarks

Current approaches to environmental LCC emphasize how the computational aspects lie in some underlying cost accounting method, e.g., ABC. It is here claimed, instead, that LCC should be self-contained and reflect the basic algebra grounded on applications of IOA that has been developed for LCA and SCM.

The input–output modeling of LCC entails the following steps: First, the manufacturing system should be represented as a process network. Then, a corresponding inventory of physical flows should be set up by using matrix notation. Two balancing procedures are then performed by means of basic linear algebra, to obtain a quantitative picture of the resources that will be required, produced, and wasted while meeting an exogenous production plan. Finally, the assignment of production costs will be carried out relying on the previously obtained grid of material and energy flows.

One possible approach could be that one proposed by Settanni et al. (2008). It also allows for introducing uncertainty and even some dynamics in the analysis.

Clearly there are differences among LCA and LCC. The latter is site-dependent and some mass balance principles may be violated to allow the I–O computational structure in order to perform some cost accounting techniques.

Nevertheless, the use of a formalized method based on matrices warrants that any former "black-box process" can be consistently represented within the computational scheme when detailed data about it are made available. This can be of help, on the one hand, if target costing is at stake or, more generally, if there is the need to transmit the

cost reduction pressures along the SC. On the other hand, the input–output approach used in LCC can support the assessment of the network profitability by managing the internal transactions properly.

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